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Venus Radar Images

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Seven new radar images of portions of Venus are presented, along with corresponding altitude contours. Each is of a circular region of 1500-km diameter located near the Venusian equator. Areal resolution is, typically, 10 × 10 km; altitude resolution is 500 m. Much structure of geologic interest is revealed.

We present here our latest results in a continuing effort to map the surface of Venus by radar. These results consist of a set of seven brightness images and corresponding altitude contours of small portions of Venus that were located at the center of the disk on the dates that the data were taken in the winter of 1973–1974. They are arranged in an equatorial belt on the one face of Venus which is always seen on the occasions of closest approach to earth.

Where the images overlap, topographic and reflectance correlations are quite high. We have included an eighth image, taken 1½ years earlier, which has appreciable overlap with one of the new set. The same topographic features can be seen in both. Also included is an 'overview' radar image of lower resolution but of greater coverage which serves as a finder chart.

The earliest Venus radar maps [*Goldstein*, 1965, 1967] were made by observing the motion of bright features across the echo Doppler spectra. Later maps were made by processing the echoes in both time delay (range) and Doppler frequency.

There is a difficulty in such an imaging system, however, in that points symmetrically placed north and south of the equator will have both the same range and the same Doppler frequency. *Rogers and Ingalls* [1969] and *Campbell et al.* [1970] have resolved this difficulty by using two receiving antennas as an interferometer. They used the phase data from the interferometer and assumed a spherical surface to resolve the north-south ambiguity.

Shapiro et al. [1972] used interferometer phase data in lunar echoes to determine altitudes. In that case, no ambiguity existed because of the large angular size of the moon relative to the antenna beam width.

The work which we report here is an extension of the interferometer technique wherein the north-south ambiguity is resolved and altitude measurements are obtained.

For these measurements we transmitted a 400-kW beam of 12.6-cm microwaves at Venus. The transmitter was mounted on the 64-m antenna at the Jet Propulsion Laboratory's Goldstone Tracking Station. After approximately 5 min of round trip flight time the antenna was switched to receive, and data were collected for 5 min of echo time. Send-receive cycles alternated for the period during which Venus was in view, from 5 to 7 h. A second receiver on a 26-m antenna, located 21.6 km to the southeast, was also used to collect interferometric data.

Signals from both receivers were processed simultaneously to divide the echoes up into arrays of range and Doppler cells. Range separation, which divides the planet into annular regions concentric with the subearth point, was possible because of rapid phase modulation of the transmitted signal. Modulation consisted of pseudorandom phase steps of 180° occurring with probability ½ every 5 μs. This gave a resolution in range of 750 m and resulted in a typical surface resolution for our images of 10 km in the north/south direction.

Separation of the echoes in the east/west direction was based on the Doppler effect, caused by the rotation of Venus about its effective spin axis. Signals passing through each range gate were Fourier-transformed to effect the Doppler separation. Near the front cap the Doppler regions are long thin strips running north and south. A frequency resolution of 1/32 Hz was used, resulting in a surface resolution (east/west) between 6 and 12 km depending on the day of the measurement. A more detailed description of the decomposition of echo power into arrays of range-Doppler cells has been published elsewhere [*Goldstein*, 1964].

During the 5-min receive cycles an array of 64 × 256 range-Doppler cells was computed every 32 s for both receivers. Each cell contained a complex number related to two patches (10 × 10 km) on the surface of Venus, one north of the effective equator and the other south (the north-south ambiguity). The phase angle of the contribution of each patch depends both upon its distance from the equatorial plane and upon the separation of the two receivers.

A maximum likelihood algorithm has been derived to estimate the reflectivities of both north and south surface patches and their distances from the equatorial plane (which are translated into altitudes) from the full set of range-Doppler data. The algorithm relies on the rotation of the earth over the time of the measurements to change the receiver locations and thereby enable the separation of the location and altitude parameters. Details of this maximum likelihood estimator have also been published elsewhere [*Rumsey et al.*, 1974]. The altitude contours which we present are referenced to the local center of curvature and hence do not necessarily relate from one image to another.

The results of the second stage of processing are the radar brightness and altitude images. First, however, we show in Figure 1 the finder map, of 85 × 85 km resolution. It was made with data collected over three radar opportunities (1969, 1970, and 1972) but with only one receiver. No altitude contours are possible with this data. The blurred strip (the 'runway') along the equator is caused by the oblique intersection of planes of constant range with the surface of Venus at the very front cap. Since the point of view, and hence the effective equator, changed slightly over the different opportunities, part of the blurring (the western part) could be removed. This artifact occurs in all of our radar images.

According to the International Astronomical Union convention the zero meridian passes through the bright feature α, increasing longitude being to the east. The grid lines mark 10° intervals. North (ecliptic) is at the top. The anomalously

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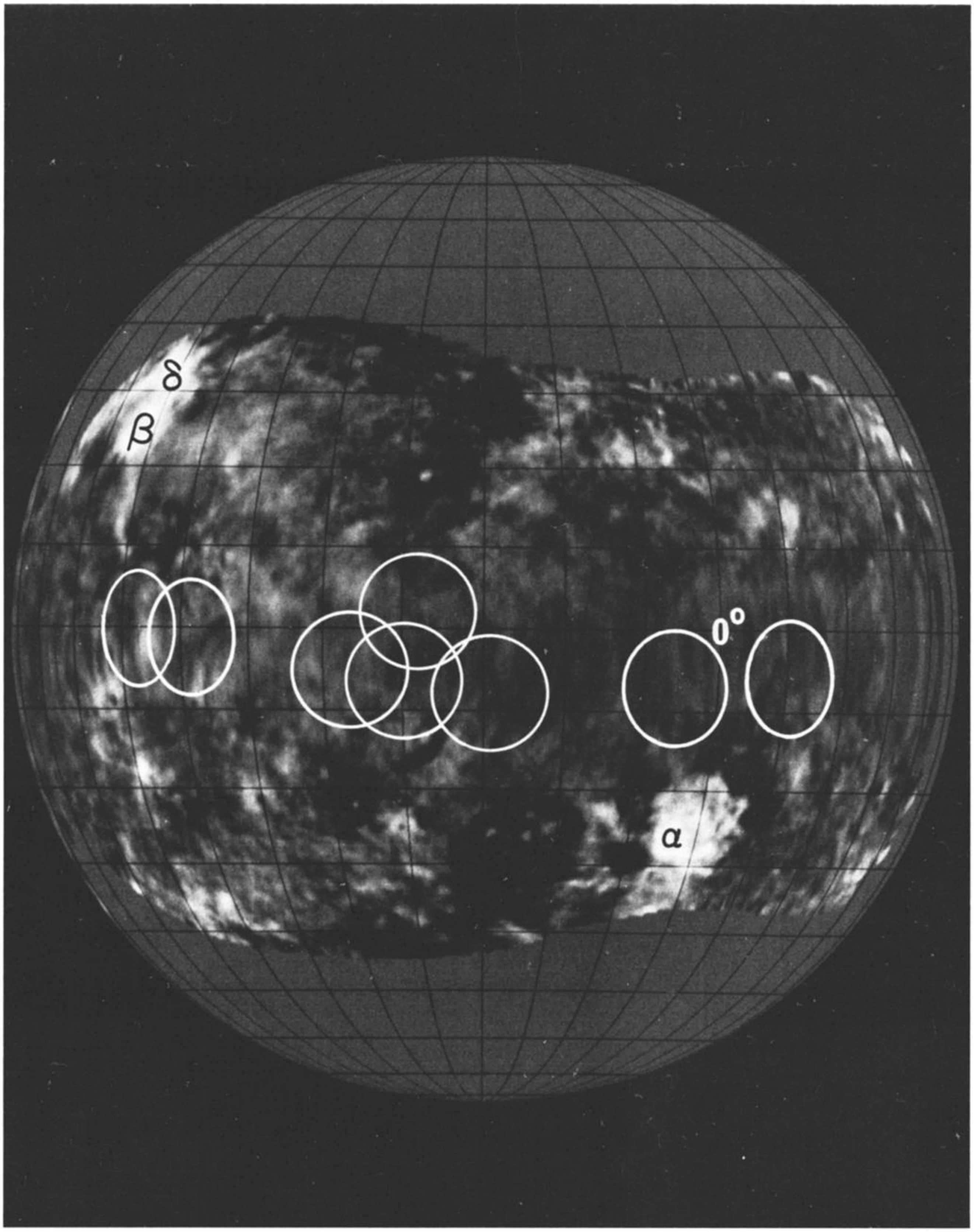

Fig. 1. An 'overview' radar brightness image of Venus of lower resolution but greater coverage than the figures to follow. Their coverage is marked by circles.

bright features α, β, and δ are known to be very rough and strongly depolarize 12.6-cm waves. Their altitude structures, however, are unknown. The areas covered by the images to follow are marked by circles on the finder map.

Figures 2–9 are the radar brightness images. In each the blurred runway has been blacked out. Near the runway the resolution cells are elongated north and south, which gives rise to a 'spinning' appearance. Halfway back, the resolution cells

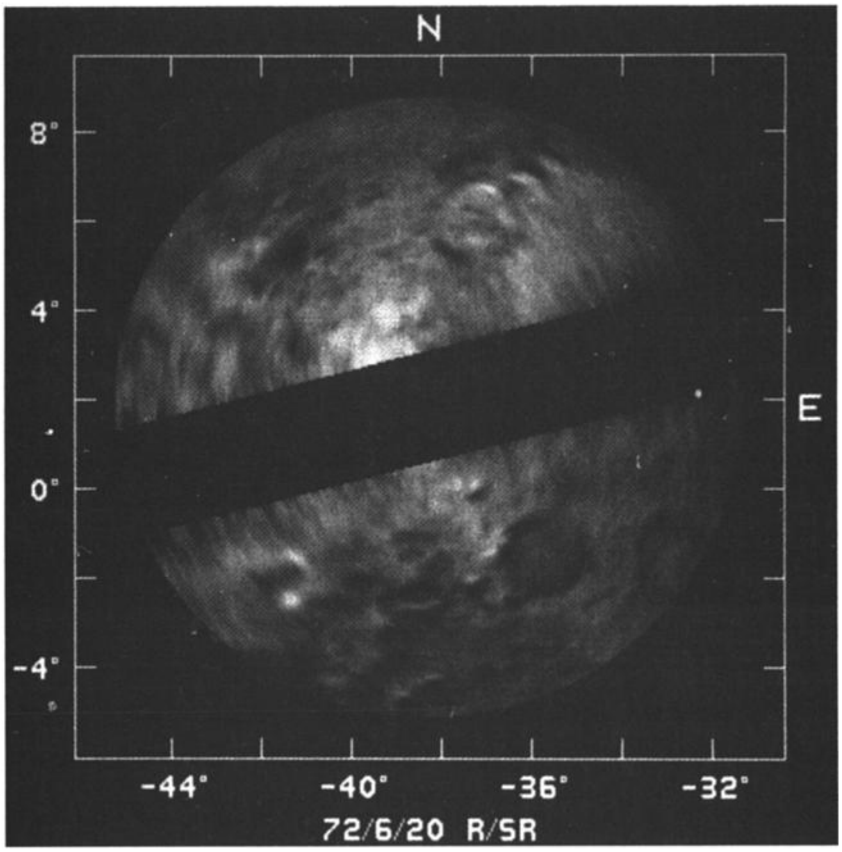

Fig. 2. Radar brightness image, taken June 20, 1972, at high resolution of small portion of Venus. The legend R/SR indicates that the figure is a reflectivity image which has been divided by the square root of the backscattering function.

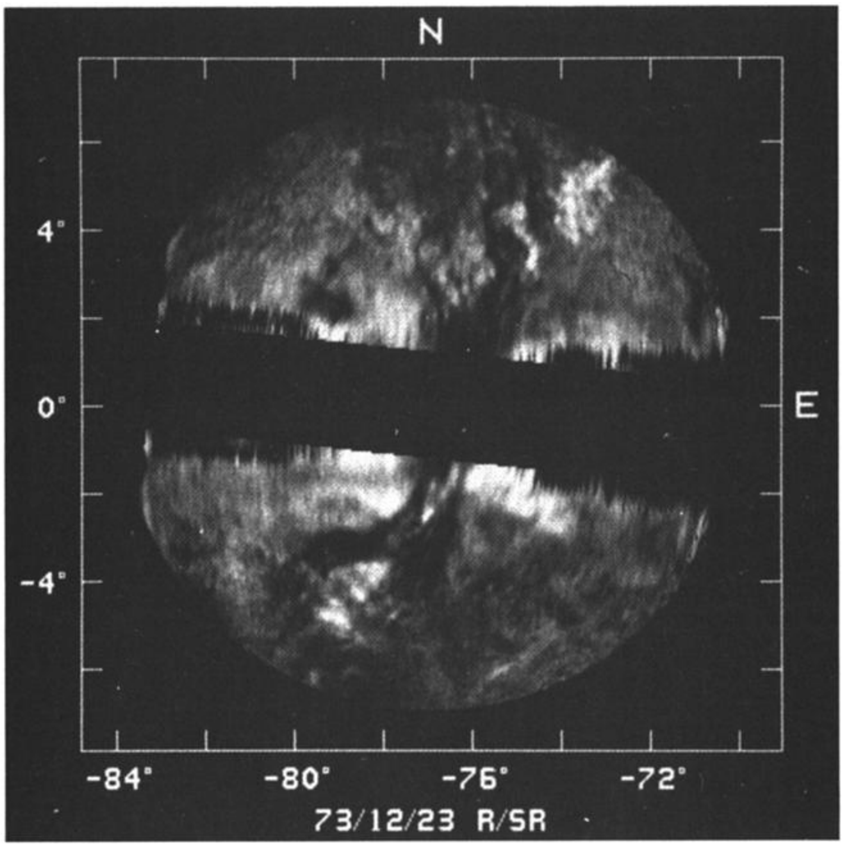

Fig. 3. First image of the new set, taken December 23, 1973.

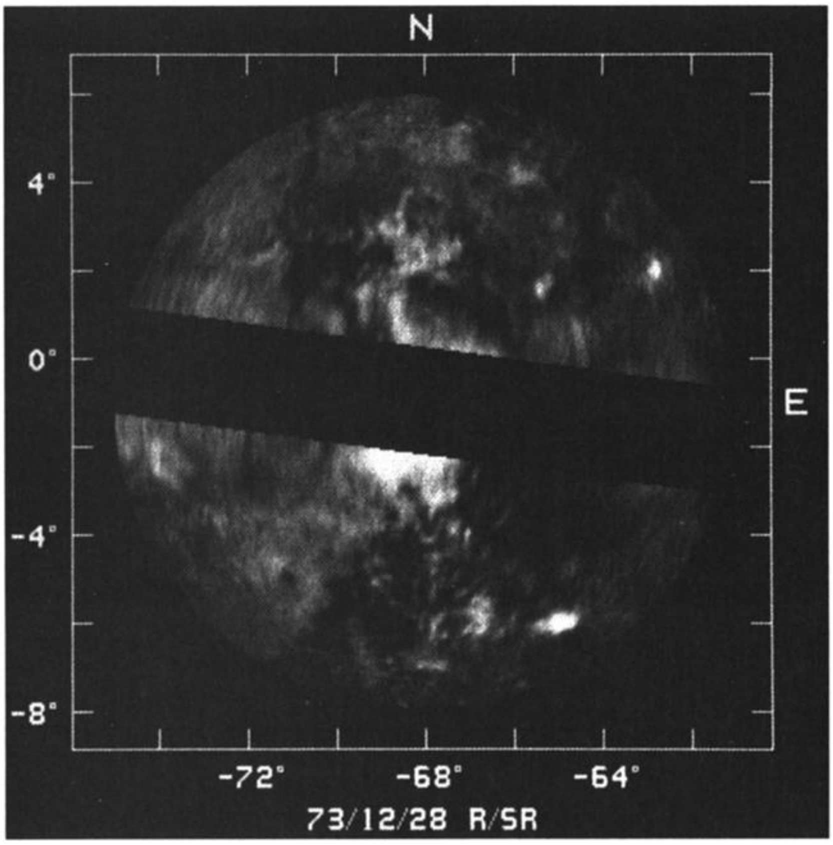

Fig. 4. Radar brightness image, taken December 28, 1973.

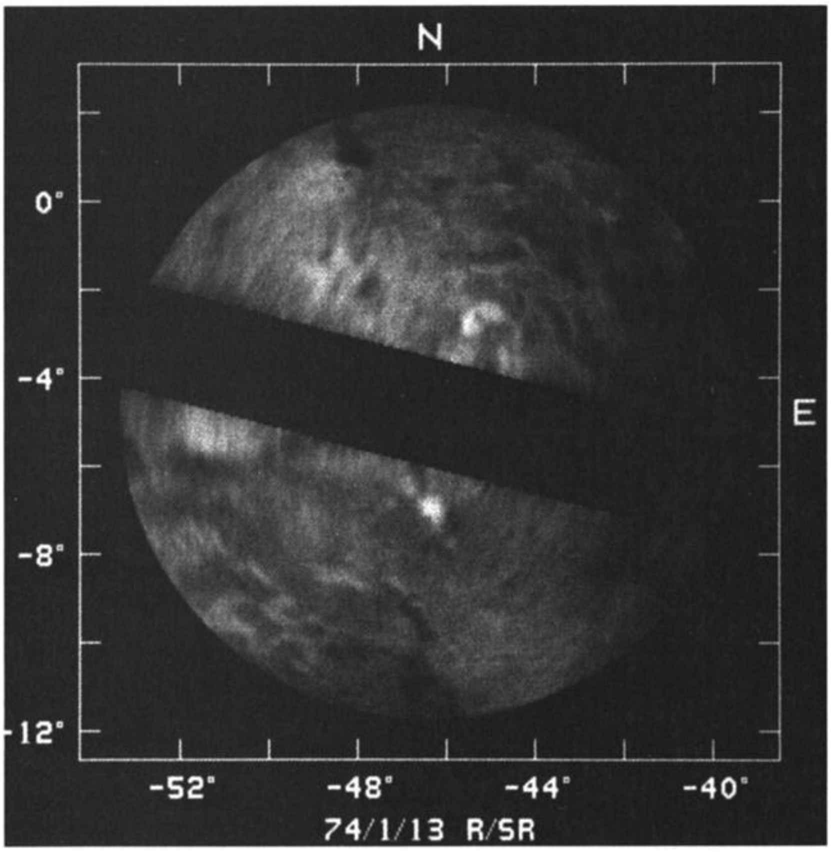

Fig. 5. Radar brightness image, taken January 13, 1974.

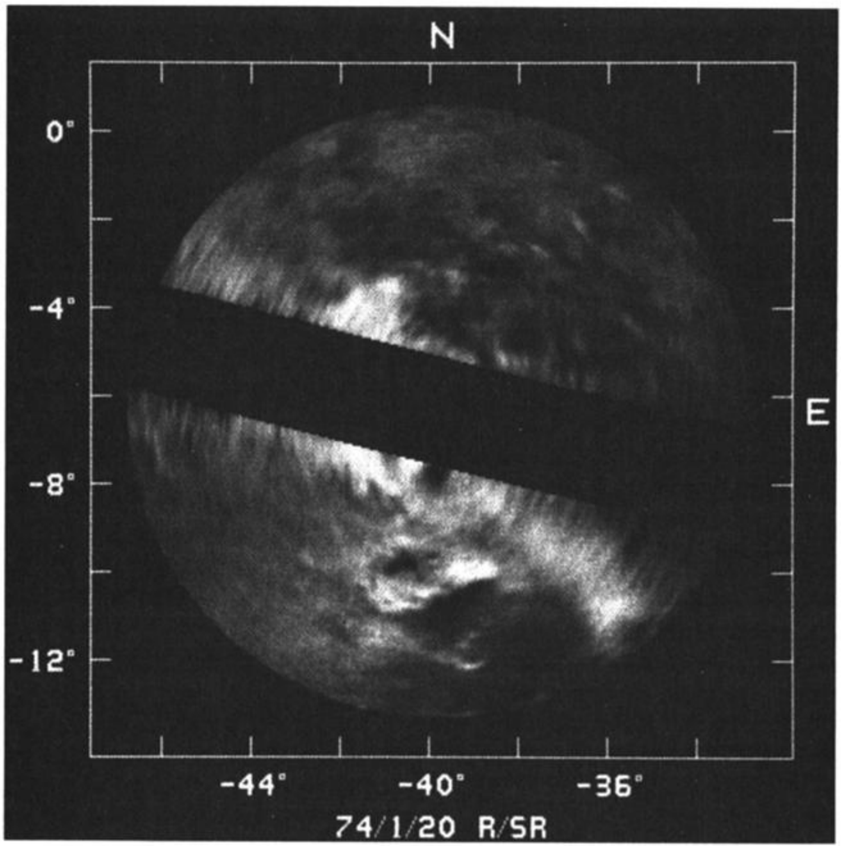

Fig. 6. Radar brightness image, taken January 20, 1974.

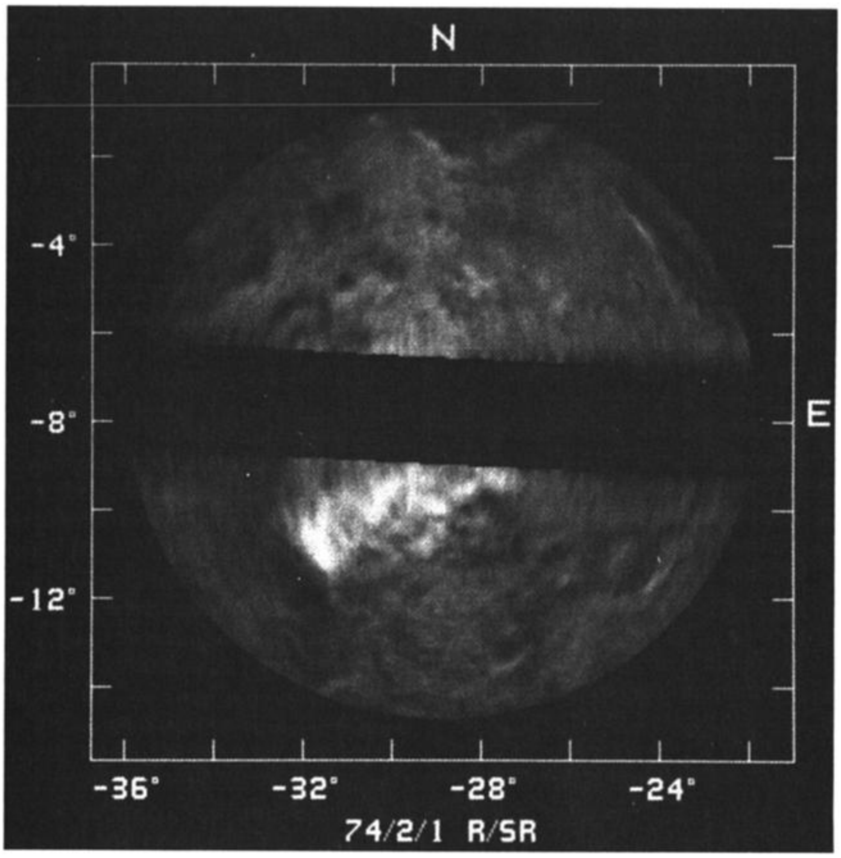

Fig. 7. Radar brightness image, taken February 1, 1974.

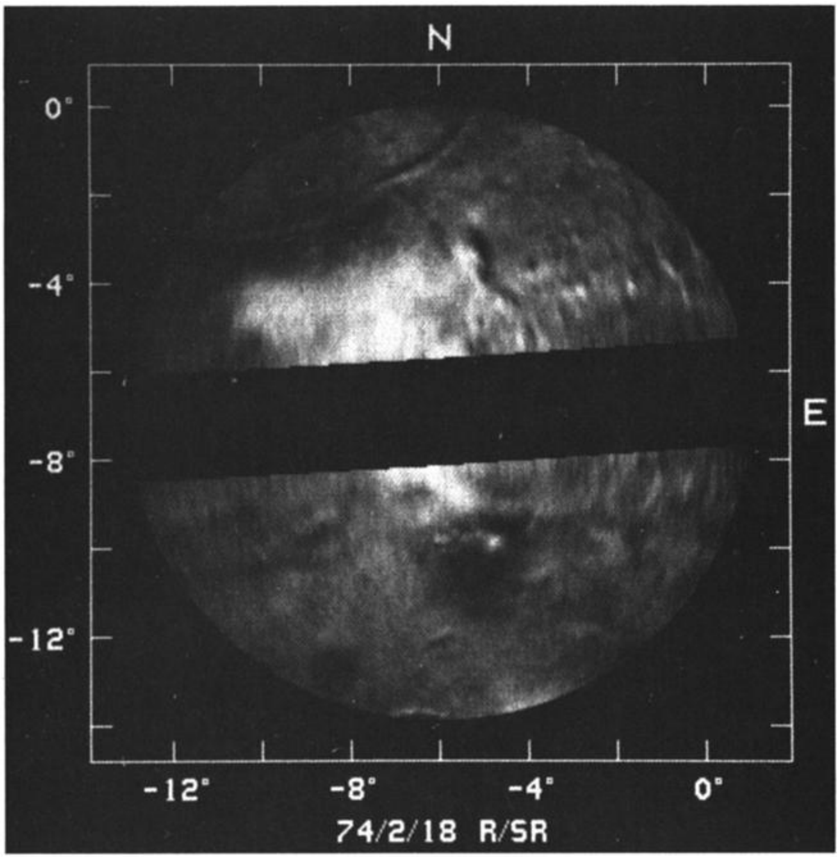

Fig. 8. Radar brightness image, taken February 18, 1974.

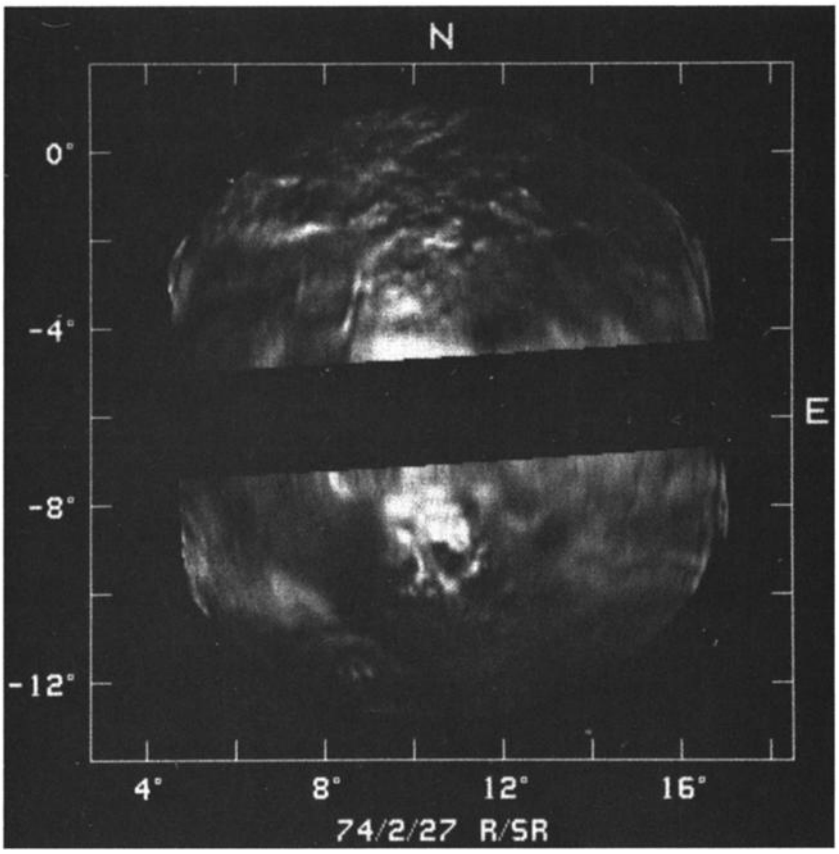

Fig. 9. Radar brightness image, taken February 27, 1974.

are about 10-km square. The strongest echo usually comes from the subearth area, where the surface is at right angles to the line of sight. Power then drops off rapidly with angular distance from that point. This generally results in a very shiny appearance, most of the power coming from a glint at the center. The average power dependence on angle of incidence is called the backscattering function. In order to reduce the dynamic range of these images we have divided the brightness of each point by the square root of the backscattering function. Some of the shiny appearance is still preserved by this technique.

Most of the brightness variations are caused by changes of slope, although changes of roughness and changes of material must also contribute to the apparent radar albedo. In many of the images a bright spot is followed, radially from the subradar point, by a dark one. We interpret this to be a hill, where the upslope is bright and the downslope dark. The reverse situation results from illuminating a depression. On some of the larger areas these interpretations are confirmed by the altitude images.

Figure 2 is from the 1972 data set. It has partial overlap with the northern part of Figure 6. The large circular feature which can be seen in each (2°S, 36°W) is about 160 km across but only about 500 m deep. It is interpreted as a crater. The smallest objects that can be resolved are 35 to 40 km across.

Figure 3 is the first of the new set. On that day the observation time was too short, resulting in an enlarged runway. This image shows a large channellike feature about 120 km wide at the equator and about 1.5 km deep running north and south across the whole picture (1500 km).

The southern part of Figure 6 contains a large 'crater' about 75 km across and 500 m deep, with the appearance of small 'craters' around the rim. No small 'craters' are seen in the adjacent areas to the south and west.

An 860-km-long curvilinear feature crosses the northwest portion of Figure 8. Altitude data have insufficient resolution to determine if it is an elevation or depression. From the brightness image it appears to be of positive relief.

Figure 9 is the last brightness image of the set. It appears to be of generally chaotic terrain.

The altitude images, presented as contours, follow in Figures 10–17. Our determinations of altitudes are much noisier than those of radar brightness. This is due partly to the geometry of the situation (the north/south projection of elevation is greatly reduced near the subearth point) and partly to the fact that, at least in the areas that we have viewed, Venus is nearly spherical. Most of the noise, however, arises from the weaker determination of altitude afforded by the maximum likelihood estimator. We have smoothed the data and present them as contours with 500-m separation. White represents high; black low. The absolute levels do not necessarily relate from one image to another.

Figure 11 shows, with magnified clarity, the effects of too short an observation time on altitude noise. The 'high' areas lining the runway are artifacts. However, the overall channel structure is revealed.

The banded structure parallel to the runway in Figure 14 is also an artifact. It was caused by inadequate change in the relative location of the two receivers with respect to Venus during the data taking interval.

Figure 17 shows a different type of artifact affecting the east and west extremes. As Venus moves away from earth, after an

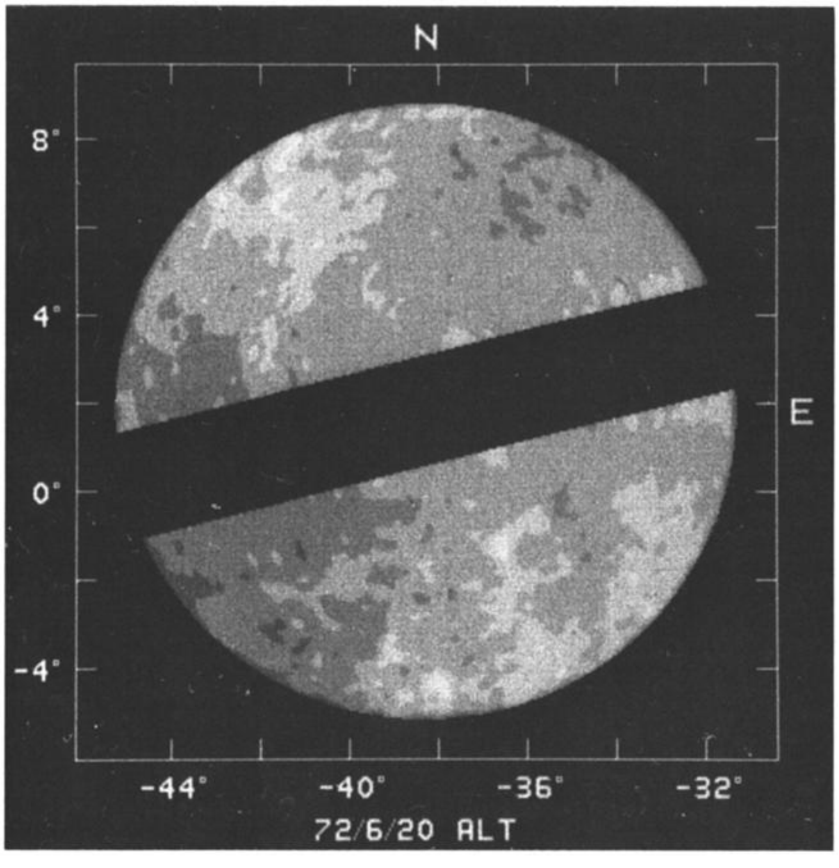

Fig. 10. Radar altitude contours. White represents high; black low. The contour separation is 500 m. The altitudes are local, being referenced to the local center of curvature. The data were taken June 20, 1972.

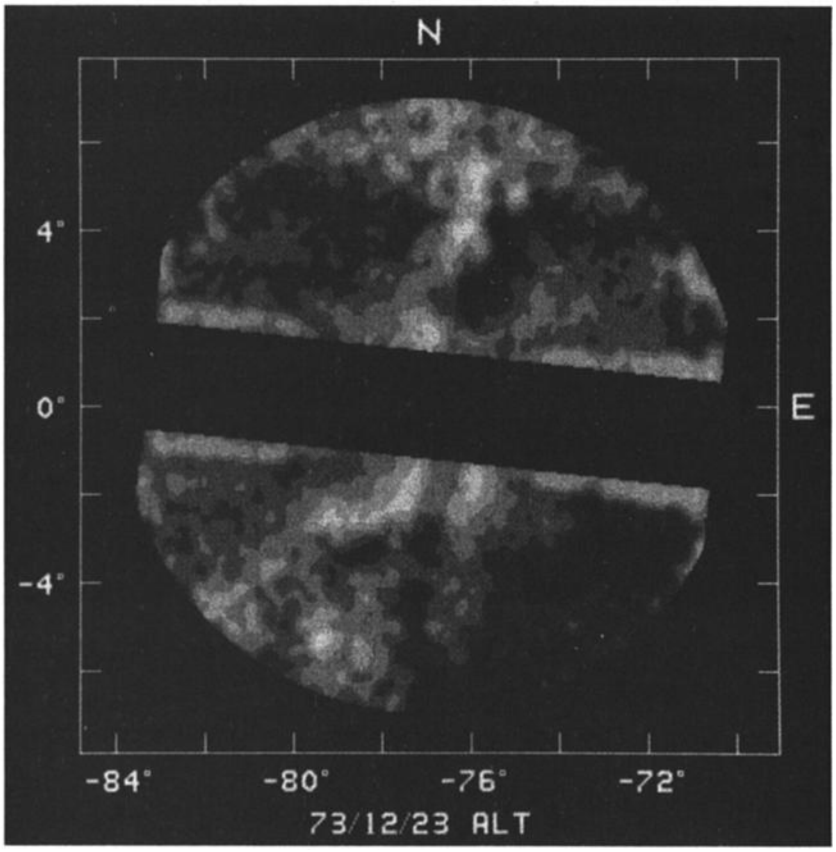

Fig. 11. Radar altitude contours, taken December 23, 1973.

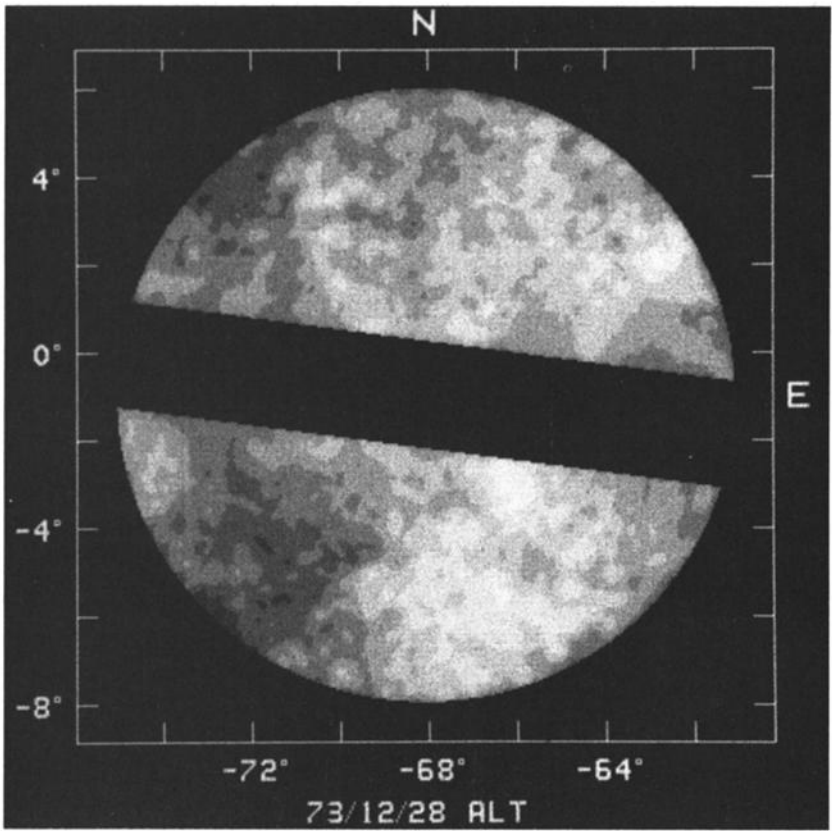

Fig. 12. Radar altitude contours, taken December 28, 1973.

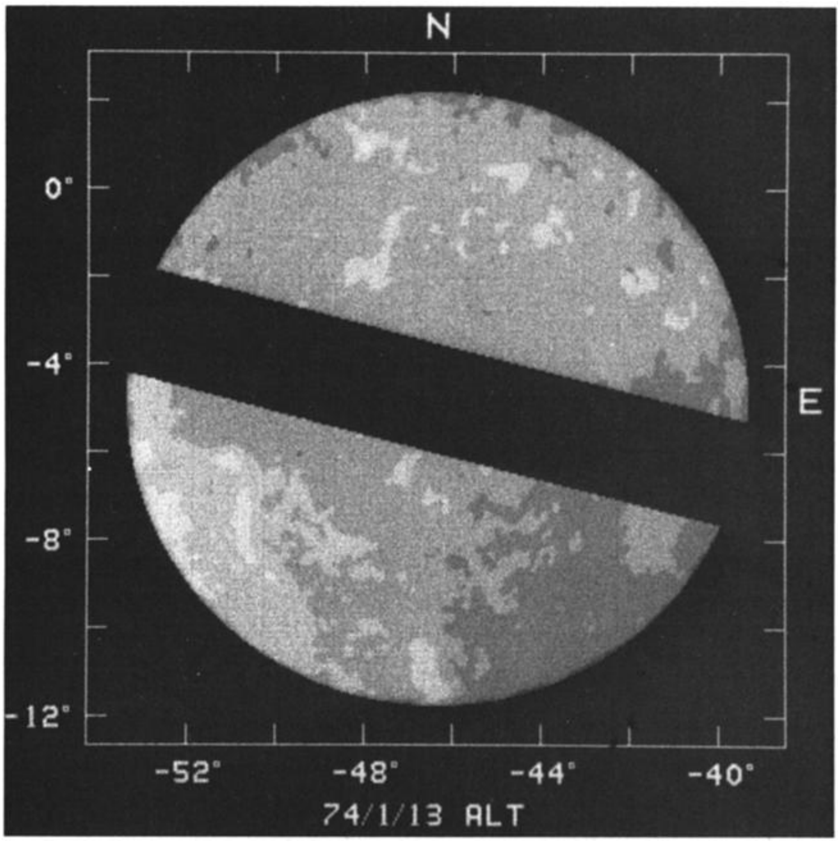

Fig. 13. Radar altitude contours, taken January 13, 1974.

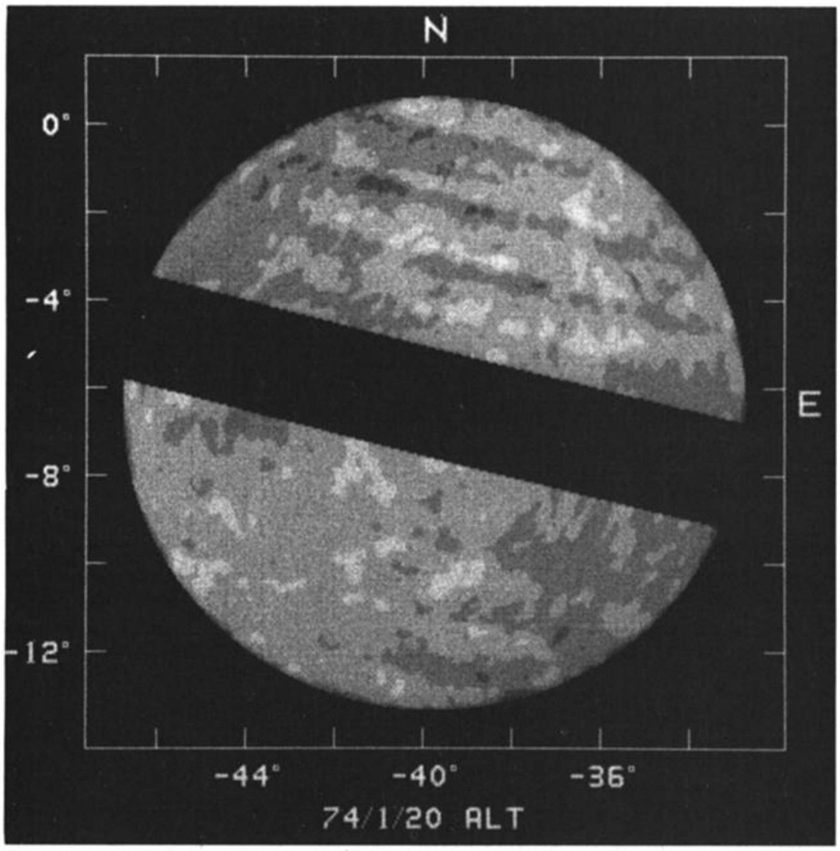

Fig. 14. Radar altitude contours, taken January 20, 1974.

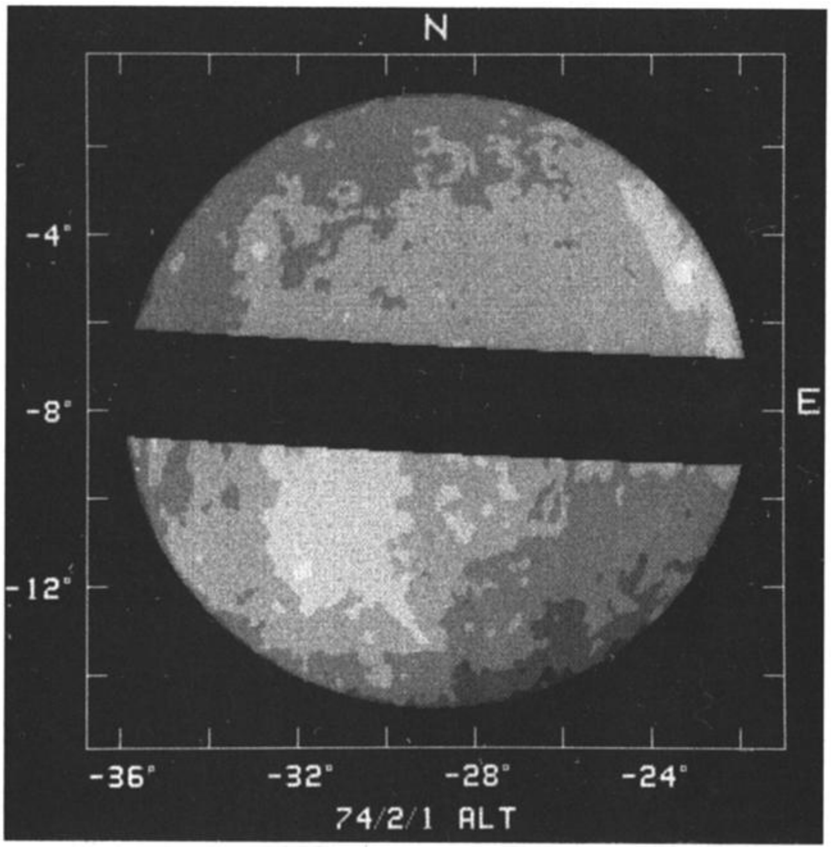

Fig. 15. Radar altitude contours, taken February 1, 1974.

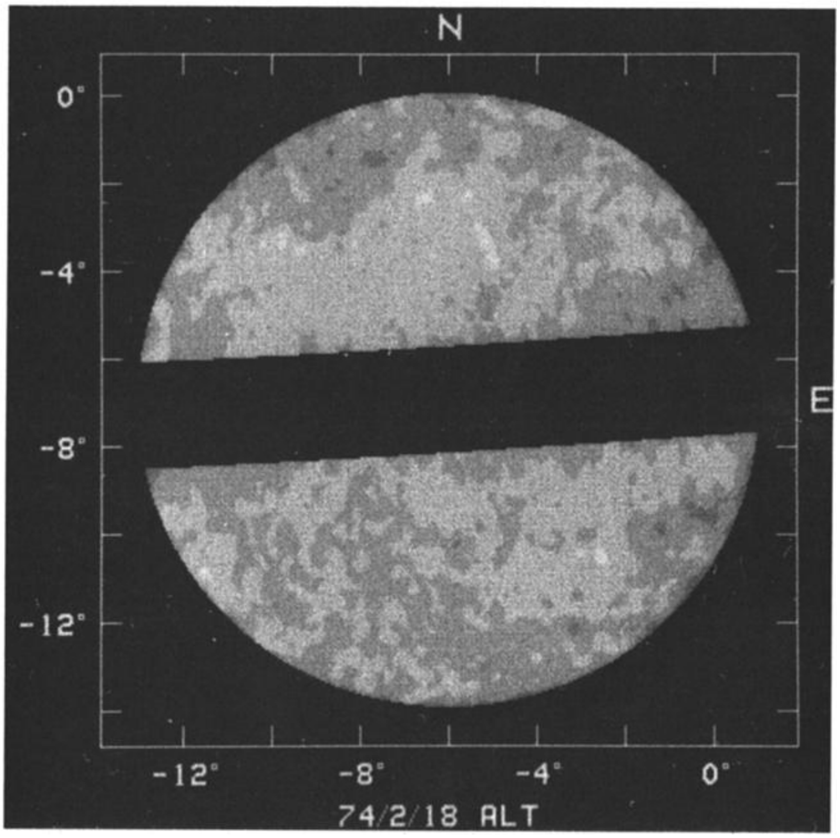

Fig. 16. Radar altitude contours, taken February 18, 1974.

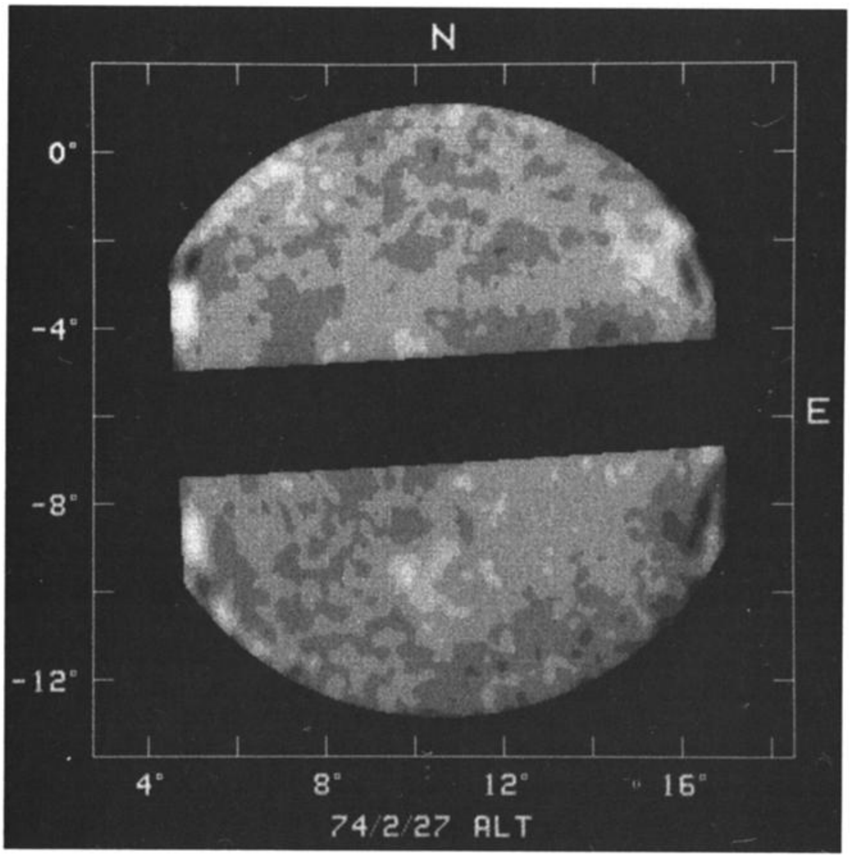

Fig. 17. Radar altitude contours, taken February 27, 1974.

inferior conjunction, its effective rotation speeds up. This increases the Doppler frequency shifts and causes, with our limited sampling speed, aliasing of the spectral edges.

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